

上海科技大学
ShanghaiTech University

EE115 Analog Circuits

Cascode AMP, IC source follower & current mirror

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Outline

- Building blocks of IC amplifier 3
 - Cascode Amplifier
 - IC Source Follower
 - Current-Mirror Circuits with Improved Performance
- Reading: SEDTRA/SMITH book pages 539-560

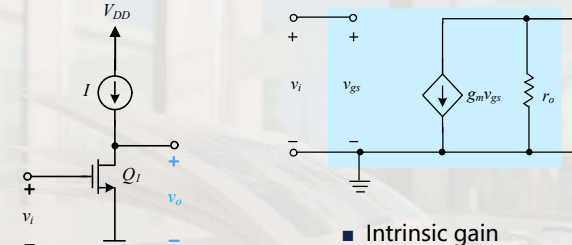
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2/16

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Review: Basic Gain Cells w/ Ideal Current Source Load

Ideal Current Source Load



$R_{in} = \infty$
 $A_{vo} = -g_m r_o$
 $R_o = r_o$

■ Intrinsic gain

$$g_m = \frac{I_D}{V_{OV}/2}$$

$$r_o = \frac{V_A}{I_D} = \frac{V_A' L}{I_D}$$

$$A_o = g_m r_o = \frac{V_A}{V_{OV}/2} = \frac{2V_A' L}{V_{OV}}$$

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3/16

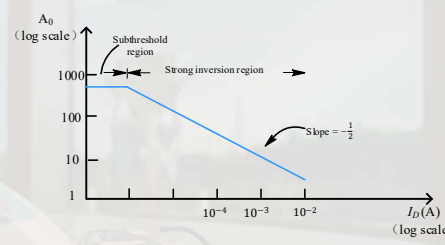
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Review: Intrinsic Gain $g_m r_o$

■ MOSFET

$$g_m = \sqrt{2\mu_n C_{ox}(W/L)}\sqrt{I_D}$$

$$r_o = \frac{V_A}{I_D} = \frac{V_A' L}{I_D}$$

$$A_o = g_m r_o = \frac{V_A' \sqrt{2(\mu_n C_{ox})(WL)}}{\sqrt{I_D}}$$


Smaller current gives higher intrinsic gain, but paid by smaller g_m and bandwidth.

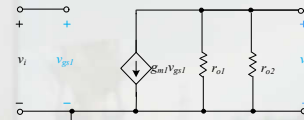
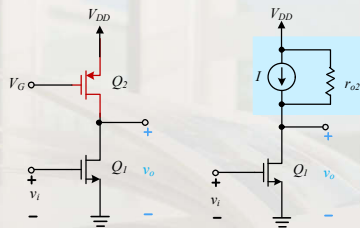
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4/16

Review: Output Resistance of Current Source Load



Current source loaded/active loaded



$$r_{o2} = \frac{|V_{A2}|}{I}$$

$$A_v \equiv \frac{v_o}{v_i} = -g_{m1}(r_{o1} || r_{o2})$$

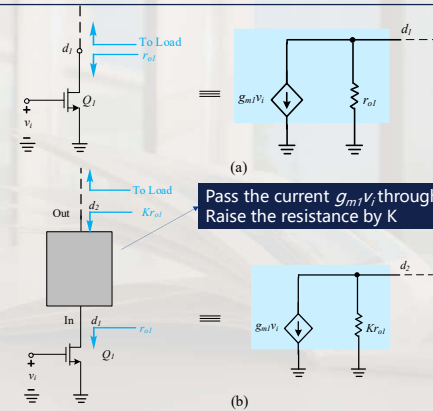
$$A_v = -\frac{1}{2} g_m r_o$$

$$I = \frac{1}{2} (\mu_p C_{ox}) \left(\frac{W}{L} \right)_2 [V_{DD} - V_G - |V_{tp}|]^2$$



5/16

Review: How To Increase Voltage Gain?



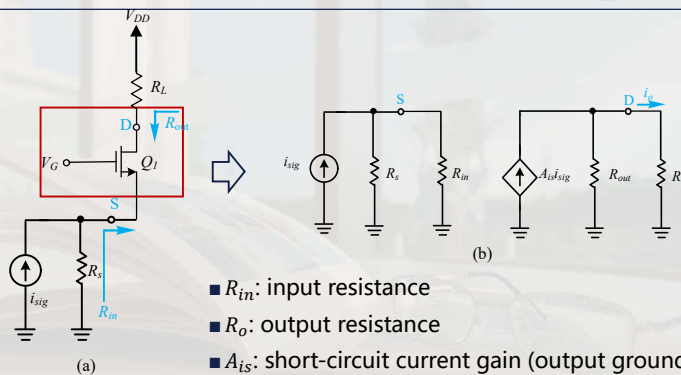
■ **Current buffer:** passes current *but* raises resistance level

- Low **input resistance**
- Unity **current gain**
- High **output resistance**

CG, CS, CD, which circuit has the best current buffer performance?

6/16

Review: Common Gate Amplifier



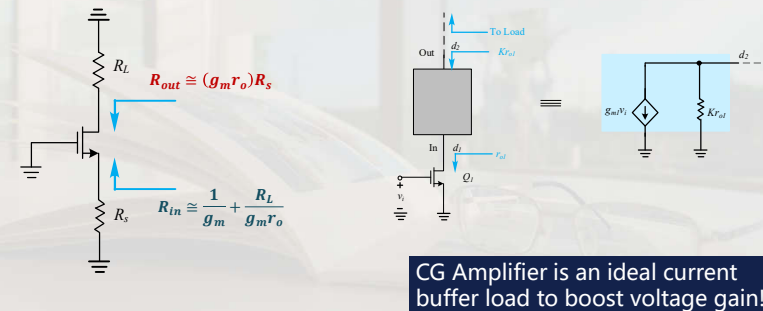
- R_{in} : input resistance
- R_o : output resistance
- A_{is} : short-circuit current gain (output grounded)

7/16

Review: Impedance Transformation of CG Amp



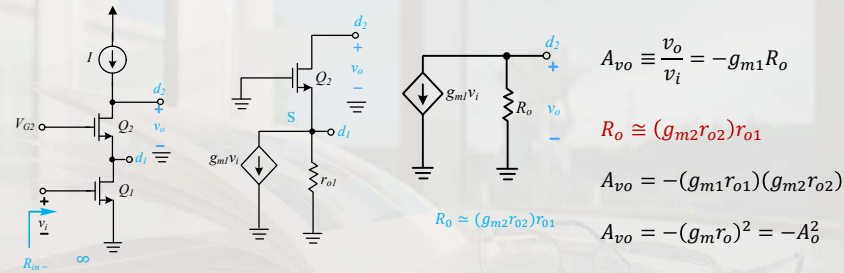
- R_s transformed to the output by multiplying by the intrinsic gain.
- R_L transformed to the input by dividing by the intrinsic gain.



CG Amplifier is an ideal current buffer load to boost voltage gain!

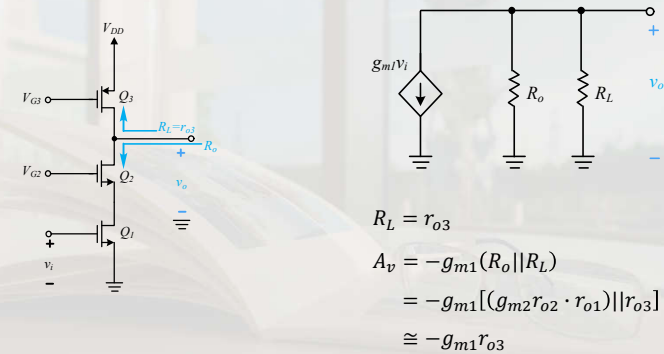
8/16

MOS Cascode Amplifier



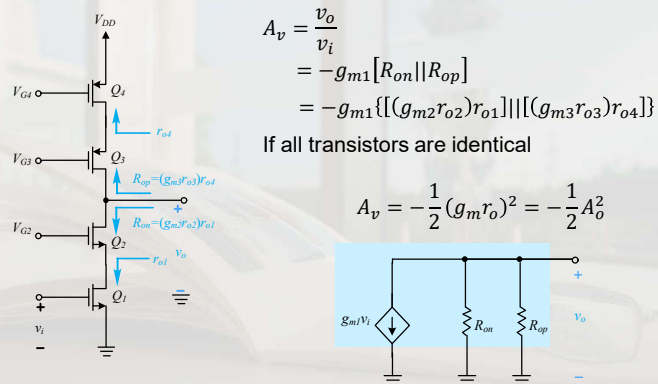
9/16

Implementation of Constant-Current Source Load



10/16

Cascode Amp w/ Cascode Current-Source Load



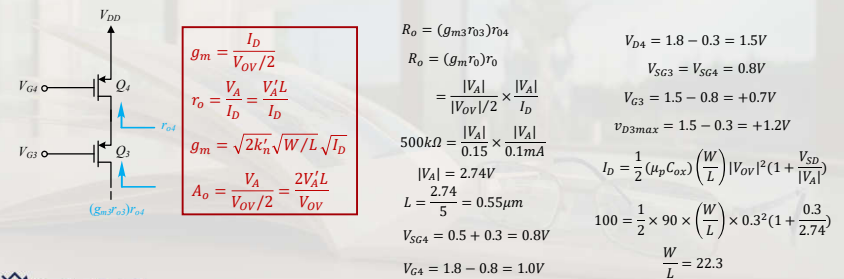
11/16

Example: Cascode current source



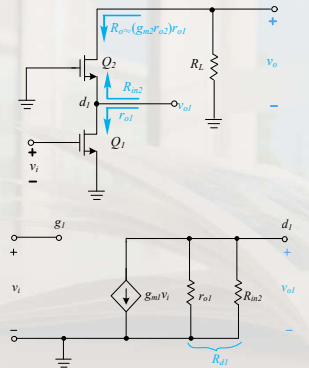
Design the Cascode current source to provide a current of 100 μA and an output resistance of 500 $\text{k}\Omega$. Given 0.18- μm CMOS technology, $v_{DD} = 1.8\text{ V}$, $v_{tp} = -0.5\text{ V}$, $\mu_p C_{ox} = 90\text{ } \mu\text{A/V}^2$, and $V_A' = -5\text{ V}/\mu\text{m}$. Use $|V_{ov}| = 0.3\text{ V}$ and determine L and W/L for each transistor, and bias voltages V_{G3} , and V_{G4} . Design to maximize the allowable signal swing at the output terminal.

Solution:



12/16

Distribution of Voltage Gain in Cascode Amp



$$A_o = -g_{m1}(R_o || R_L)$$

$$A_o = -g_{m1}(g_{m2}r_{o2}r_{o1} || R_L)$$

$$A_v = A_{v1}A_{v2} = \left(\frac{v_{o1}}{v_i}\right)\left(\frac{v_o}{v_{o1}}\right)$$

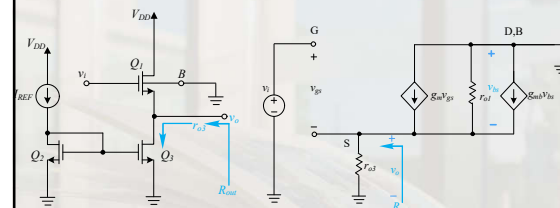
$$A_{v1} = \frac{v_{o1}}{v_i} = -g_{m1}R_{d1} = -g_{m1}(r_{o1} || R_{in2})$$

$$R_{in2} \approx \frac{R_L}{g_{m2}r_{o2}} + \frac{1}{g_{m2}}$$

Case	R_L	R_{in2}	R_{d1}	A_{v1}	A_{v2}	A_v
1	∞	∞	r_{o1}	$-g_{m1}r_{o1}$	$g_{m2}r_{o2}$	$-(g_{m1}r_{o1})^2$
2	$(g_{m2}r_{o2})r_{o1}$	r_{o1}	$r_{o1}/2$	$-\frac{1}{2}(g_{m1}r_{o1})$	$g_{m2}r_{o2}$	$-\frac{1}{2}(g_{m1}r_{o1})^2$
3	r_{o1}	$\frac{2}{g_{m2}}$	$\frac{2}{g_{m2}}$	-2	$\frac{1}{2}(g_{m2}r_{o2})$	$-(g_{m1}r_{o1})$
4	$0.2r_{o1}$	$\frac{1.2}{g_{m2}}$	$\frac{1.2}{g_{m2}}$	-1.2	$0.17(g_{m2}r_{o2})$	$-0.2(g_{m1}r_{o1})$

13/16

IC Source Follower

Body effect coefficient: $g_{mb} = \chi g_m$

$$\frac{v_o}{v_i} = \frac{R_L}{R_L + \frac{1}{g_m}}$$

$$R_L = r_{o1} || r_{o3} || \frac{1}{g_{mb}}$$

$$R_L \approx \frac{1}{g_{mb}}$$

$$\frac{v_o}{v_i} \approx \frac{g_m}{g_m + g_{mb}} = \frac{1}{1 + \chi}$$

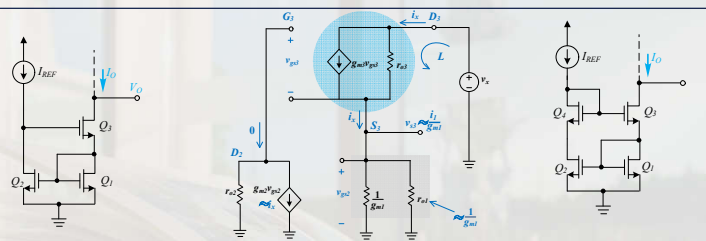
$$R_{out} = \frac{1}{g_m} || \frac{1}{g_{mb}} || r_{o1} || r_{o3}$$

$$\approx \frac{1}{(g_m + g_{mb})} = \frac{1}{(1 + \chi)g_m}$$



14/16

Wilson MOS Mirror



$$R_o \equiv \frac{v_x}{i_x}$$

$$v_{gs2} \approx i_x / g_{m1}$$

$$g_{m2}v_{gs2} = g_{m2} \frac{i_x}{g_{m1}} = i_x$$

$$v_{g3} = v_{d2} = -i_x r_{o2}$$

$$v_{gs3} = v_{g3} - v_{s3} = v_{d2} - v_{gs2} = -i_x r_{o2} - \frac{i_x}{g_{m1}} \approx -i_x r_{o2}$$

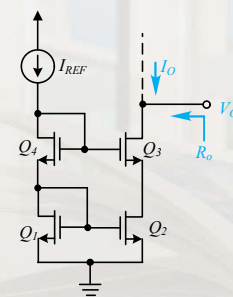
$$g_{m3}v_{gs3} \approx -(g_{m3}r_{o2})i_x$$

$$v_x = (i_x + g_{m3}r_{o2}i_x)r_{o3} + \frac{i_x}{g_{m1}}$$

$$R_o \equiv \frac{v_x}{i_x} = (g_{m3}r_{o3})r_{o2} + r_{o3} + \frac{1}{g_{m1}} \approx (g_{m3}r_{o3})r_{o2}$$

15/16

Cascode MOS Mirror



$$R_o \approx g_{m3}r_{o3}r_{o2}$$

Pro: output resistance increased by $g_{m3}r_{o3}$ **Con:** consumes a large portion of steadily shrinking supply voltage

16/16